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SHORT REPORT

Potential distribution of *Tridentiger barbatus* (Günther 1861) and *Tridentiger nudicervicus* (Tomiyama 1934) in the Seto Inland Sea, western Japan

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Abstract We developed distribution models for two near-threatened gobiid fishes, *Tridentiger barbatus* and *Tridentiger nudicervicus*, based on distribution data and geographic variables in the Ariake Sea, the Yatsushiro Sea, and Suonada Bay. Subsequently, we estimated the potential distribution of both species across all areas of the Seto Inland Sea based on the model predictions. The models indicated high accuracy and demonstrated that both species inhabit shoal and relatively enclosed waters. Predicted potential distribution areas of the two species included all sites with previous records and a few new sites without existing records.

Keywords SDM · Goby · Tidal flat · Maxent · GIS

Introduction

Tridentiger barbatus (Günther 1861) and *Tridentiger nudicervicus* (Tomiyama 1934) are gobiid fishes that are mainly distributed in bays that have large tidal flats in western Japan (e.g., the Ariake Sea) (Dôtu 1957, 1958; Akihito et al. 2013). Both species are listed as near

threatened (NT) in the Red List (Japan Ministry of the Environment 2013).

In the Seto Inland Sea, *T. barbatus* has been recorded in Hyogo, Okayama, Hiroshima, Fukuoka, and Kagawa prefectures (Hatooka 2000; Egi 2009; Hyogo Freshwater Biology Society 2011; National Land with Water Information Data Management Center 2011; Tokushima Prefectural Museum 2013). In comparison, *T. nudicervicus* has been recorded in Hyogo, Okayama, Yamaguchi, Fukuoka, and Kagawa prefectures (Yokogawa 1996; Hatooka 2000, 2002; Egi 2009; Inui 2009; Tokushima Prefectural Museum 2013). Thus, both species are widely distributed in the Seto Inland Sea. Yet, when the observation sites of the two species are presented on a map, the sites are broadly scattered. This observation may indicate that the habitats used by the two species have not been clarified, despite being widespread. If this theory is correct, it is possible that the lack of accurate habitat information may increase the extinction risk of each species.

Geographical Information System (GIS) and Species Distribution Models (SDMs) are effective tools that may be implemented to help managers mitigate such risks. With the rise of several powerful statistical techniques and GIS tools, SDMs have rapidly developed in the field of ecology. Such models are static and probabilistic in nature, as they statistically relate the geographical distribution of species or communities to their present environment (Guisan and Zimmermann 2000; Kozak et al. 2008). These models have been applied to terrestrial conservation and restoration programs, providing an effective first step toward establishing land management priorities (Scott et al. 2002). In recent years, studies of freshwater fishes using SDMs based on GIS have been increasing in Japan (Kano et al. 2010; Sato et al. 2010; Onikura et al. 2012). However, previous research focusing on shallow water fishes had been limited

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to species considered as important fishery resources such as red sea bream and flounder (Hori 2012).

This study aimed to develop SDMs for *T. barbatus* and *T. nudicervicus* in an area where detailed presence information was available, and project the models of two species in an area with poor presence data. The models of two species were developed using information about the presence of the two species and specific geographic variables in the Ariake Sea, the Yatsushiro Sea, and Suonada Bay (west part of Seto Inland Sea), and projects the models of two species across all areas of Seto Inland Sea. Then, we generated potential habitat maps and identified possible habitats for the two species.

Materials and methods

During surveys carried out between 2005 and 2012 in the Ariake Sea, the Yatsushiro Sea, and Suonada Bay, we collected *Tridentiger barbatus* and *T. nudicervicus* at 19 (Ariake: 6; Yatsushiro: 6; Suonada: 7) and 38 sites (Ariake: 9; Yatsushiro: 13; Suonada: 16) in total, respectively (Table 1, Fig. 1). In addition, the latitude and longitude of the sites are presented with two digits in Table 1, to provide the approximate location. We used these data as training samples for SDMs.

The depth, slope, and area of the bay units (Arakida et al. 2011) were used as environmental predictors. The digital depth model (50-m grid size) was created from Bathymetry Digital Data (M7000, Japan Hydrographic Association; obtainable from <http://www.jha.or.jp/jp/shop/products/btdd/>, accessed 15 May 2013). The mean values of the depth and slope at around 1 km (D1, S1), 3 km (D3, S3), and 6 km (D6, S6) were calculated using Focal Statistics (ArcGIS 10 + Spatial Analyst, ESRI).

The bay unit was used as an indicator of how enclosed the sea area was (Arakida et al. 2011). In a previous study, potential shorebird habitats at broad scales were predicted with considerable accuracy by using the bay unit indicator (Arakida et al. 2011). The bay units were extracted from the coastal lines provided by the National Land Numerical Information download service (http://nlftp.mlit.go.jp/ksj-e/gml/gml_datalist.html, accessed 15 May 2013). First, a buffer was created at X km from the coastline toward the sea area (Buffer 1); then another buffer was created at X km from Buffer 1 toward the coastline (Buffer 2). The area between Buffer 2 and the coastline was then defined as a bay unit (Fig. 2). If there was a wide-open sea area in the bay, Buffer 1 became a doughnut polygon. In these situations, “open-hole bays” and “closed-hole bays” were examined (Arakida et al. 2011) (Fig. 3). Following Arakida et al. (2011), three different scales (1 km, 3 km, and 6 km) were prepared. Both open-hole (BO) bays and closed-hole

(BC) bays were extracted for each of these three scales (1 km: BO1, BC1; 3 km: BO3, BC3; and 6 km: BO6, BC6).

Maximum entropy modeling (Maxent: Phillips et al. 2006) was used for the analysis, which is an automated learning method that estimates the most uniform distribution (maximum entropy) across the study area, given the constraint that the expected value of each environmental predictor under this estimated distribution matched the empirical average. This method was selected because it only requires presence data. In addition, the performance of this model has been proven to be more reliable compared to other distribution-modeling techniques, particularly those with small sample sizes (Elith et al. 2006; Hernandez et al. 2006). In addition, this model is able to incorporate the non-linearity of environmental variables (Phillips et al. 2006). The performance of the models was evaluated using the area under the curve (AUC) approach, with receiver operating characteristic analysis (Fielding and Bell 1997). The accuracy of the models was evaluated using sensitivity, by means of maximum training sensitivity plus specificity logistic thresholds (Manel et al. 2001). The importance of each predictor variable was evaluated by its contribution to the gain of the models.

Subsequently, the models were projected to produce potential habitat maps for the two species across the entire area of the Seto Inland Sea. The predicted area was limited to waters that were extracted by BC6, which extracted the principal bays in Japan (Arakida et al. 2011). In addition, when the maps were produced, the maximum probability of each species occurring in each 3-km grid was presented in order of visualization. We then used the potential habitat maps to confirm whether potential habitats matched the previous distribution records of the two species. In addition, we conducted field surveys at four sites where potential habitats were predicted, but where previous records were not available.

A geographic information system (GIS: ArcGIS 9.3, 10 + Spatial Analyst, ESRI) was used to prepare the spatial data of the environmental parameters and species distributions, in addition to mapping the potential habitats. Maxent version 3.3.3 was used for the data analysis and to calculate AUC and thresholds.

Results and discussion

Factors affecting species distributions. On the basis of the results of Maxent, the AUC values and sensitivities were high for both species (> 0.9 and 90 %, respectively, Table 2). These results demonstrate that simple predictors, such as coastlines and the digital depth model, may be strongly related to the presence of the two species in

Table 1 Collection sites of *Tridentiger barbatus* and *T. nudicervicus* in the Ariake Sea, the Yatsushiro Sea, and Suonada Bay

Bay	Prefecture	Site	Latitude (°N)	Longitude (°E)	<i>T. barbatus</i>	<i>T. nudicervicus</i>
Suonada	Yamaguchi	Koya R.	34.05	131.04	+	
Suonada	Yamaguchi	Kanda R.	34.04	131.03		+
Suonada	Yamaguchi	Fushino R.	34.03	131.39	+	+
Suonada	Yamaguchi	Doroishi R.	34.03	131.39	+	
Suonada	Yamaguchi	Asa R.	34.00	131.15		+
Suonada	Yamaguchi	Ariho R.	33.99	131.16		+
Suonada	Fukuoka	Okuhata R.	33.92	131.00		+
Suonada	Fukuoka	Hishakuda	33.90	131.00		+
Suonada	Fukuoka	Ikawa	33.90	130.99	+	+
Suonada	Fukuoka	Chikuma R.	33.83	130.97	+	+
Suonada	Fukuoka	Nuki R.	33.83	130.97	+	+
Suonada	Fukuoka	Kusami R.	33.81	130.98	+	+
Suonada	Fukuoka	Nagao R.	33.75	131.01		+
Suonada	Fukuoka	Harai R.	33.73	131.01		+
Suonada	Oita	Hane R.	33.66	131.50		+
Suonada	Oita	Yamakuni R.	33.62	131.20		+
Suonada	Oita	Ooshinden	33.61	131.23		+
Suonada	Oita	Yorimo R.	33.57	131.43		+
Ariake	Saga	Shiota R.	33.11	130.14	+	+
Ariake	Saga	Kashima R.	33.10	130.13	+	
Ariake	Saga	Itoki R.	33.02	130.19	+	+
Ariake	Nagasaki	Imazato R.	32.96	130.20		+
Ariake	Nagasaki	Izaki	32.94	130.20		+
Ariake	Nagasaki	Koujiro R.	32.87	130.27		+
Ariake	Nagasaki	Saigo R.	32.87	130.23		+
Ariake	Nagasaki	Yue R.	32.86	130.33		+
Ariake	Fukuoka	Shiotsuka R	33.10	130.39	+	+
Ariake	Kumamoto	Sakai R.	32.89	130.50	+	+
Ariake	Kumamoto	Midori R.	32.71	130.59	+	
Yatsushiro	Kumamoto	Omi R.	32.62	130.59	+	+
Yatsushiro	Kumamoto	Sokoe R.	32.62	130.56	+	+
Yatsushiro	Kumamoto	Hi R. 1	32.62	130.63	+	
Yatsushiro	Kumamoto	Hi R. 2	32.61	130.62		+
Yatsushiro	Kumamoto	Satoura R.	32.62	130.54	+	+
Yatsushiro	Kumamoto	Suna R.	32.62	130.65	+	+
Yatsushiro	Kumamoto	Kounoura R.	32.61	130.51		+
Yatsushiro	Kumamoto	Kagami R.	32.59	130.61		+
Yatsushiro	Kumamoto	Ozaya R.	32.57	130.59		+
Yatsushiro	Kumamoto	Mizunashi R.	32.56	130.58		+
Yatsushiro	Kumamoto	Kuma R. 1	32.50	130.56		+
Yatsushiro	Kumamoto	Kuma R. 2	32.50	130.54		+
Yatsushiro	Kumamoto	Kuma R. 3	32.47	130.56	+	
Yatsushiro	Kumamoto	Hinagumagoshi	32.43	130.56		+
Yatsushiro	Kumamoto	Futami R.	32.42	130.54		+

Plus sign indicates occurrence of species

Fig. 1 Collection locations of *Tridentiger barbatus* and *T. nudicervicus* in the Ariake Sea, the Yatsushiro Sea, and Suonada Bay

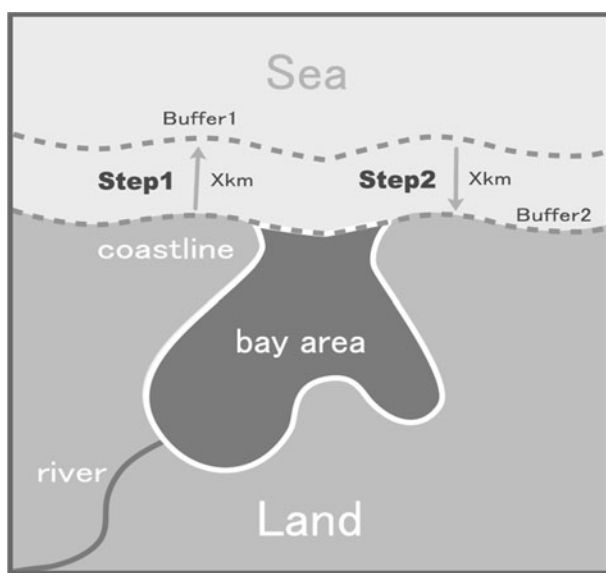
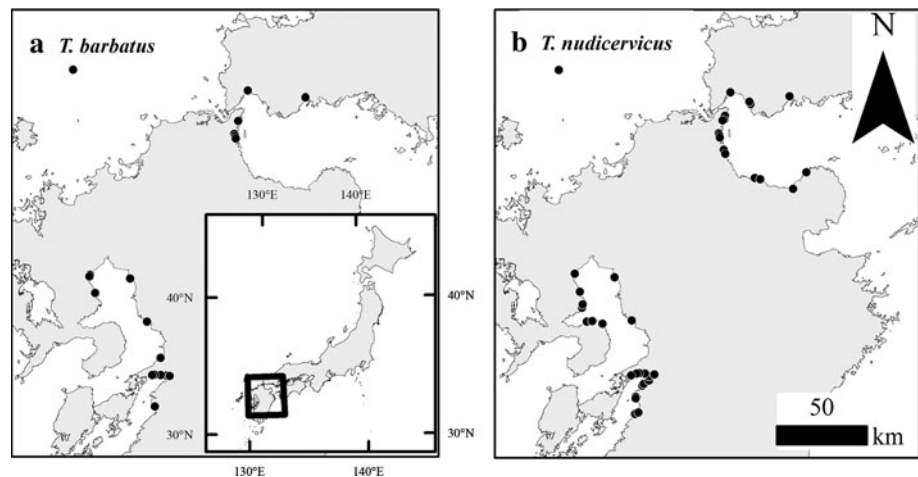


Fig. 2 Bay unit procedure extracted from Arakida et al. (2011). Step 1: a buffer was created at X km from the coastline toward the sea area (Buffer 1). Step 2: another buffer was created at X km from Buffer 1 toward the coastline (Buffer 2). The area between Buffer 2 and the coastline was defined as a bay unit. The bay unit was extracted if half the distance of the bay mouth was less than the buffer width

the Ariake Sea, the Yatsushiro Sea, and Suonada Bay. Therefore, this method might be applicable for other fishes and invertebrates inhabiting shallow waters and/or tidal flats.

For both species, the mean water depth had the highest contribution to the gain of the models, with that of D3 being the highest for *Tridentiger barbatus* and D1 the highest for *T. nudicervicus* (Table 2). Furthermore, the response curve of *T. barbatus* decreased, while that of *T. nudicervicus* followed a convex curve (Fig. 4d, e). These results show that both species inhabit shallow waters, but that *T. barbatus* inhabits relatively extensive shallow habitats compared to *T. nudicervicus*.

For both species, the environmental variables BO1, BO3, and BO6 contributed more than 5 %, with the response curve of these variables following a convex curve. The response curves of BO3 and BO6 had a similar shape for both *T. barbatus* and *T. nudicervicus* (Fig. 4b, c). However, for *T. nudicervicus*, the response curve of BO1 decreased sharply with increasing BO1. In comparison, for *T. barbatus*, the BO1 response curve decreased slightly with increasing BO1 (Fig. 4a). BO1 represents the areas of the bay where the mouth width was less than 2 km. Thus, this result shows that the probability of occurrence of *T. nudicervicus* declined in bays with small mouths and large areas. The degree of enclosure increases with increasing bay area and decreasing bay mouth size (International EMECS Center 2013). In addition, enclosed bays easily trap sediments, because the sea area is protected from ocean swells, with few tidal currents or locally wind-generated waves (Golbuu et al. 2003). Previous studies have shown that *T. barbatus* preferentially inhabits muddy flats, while *T. nudicervicus* preferentially inhabits relatively hard sand–mud flats at the site scale (Dôtu 1957, 1958). On the basis of these information, we expect that mud flats, which are the main habitat of *T. barbatus*, primarily form in enclosed and extensive shallow waters, while sand–mud flats, which are the main habitat of *T. nudicervicus*, primarily form in shallow and relatively open waters. Consequently, the two species exhibit different patterns of distribution.

Mapping potential species habitats in the Seto Inland Sea. The potential habitat maps for the two species are shown in Fig. 5. Six sites with previous records for *T. barbatus* and four sites with previous records for *T. nudicervicus* were consistent with the potential habitat predicted for each species by SDMs. These results indicate that the predicted distribution of the two species in the Seto Inland Sea reflected their actual distributions. In addition, we located new sites inhabited by *T. barbatus* (1 site) and

Fig. 3 Open- and closed-hole bays extracted from Arakida et al. (2011). The presence of an open sea area in a bay caused the buffer to become a doughnut polygon. **a** Open-hole bay: this bay unit represents the proximity of land areas; small-scale bay in the big bay is extracted. **b** Closed-hole bay: this bay unit represents the width of the bay mouth facing the open sea

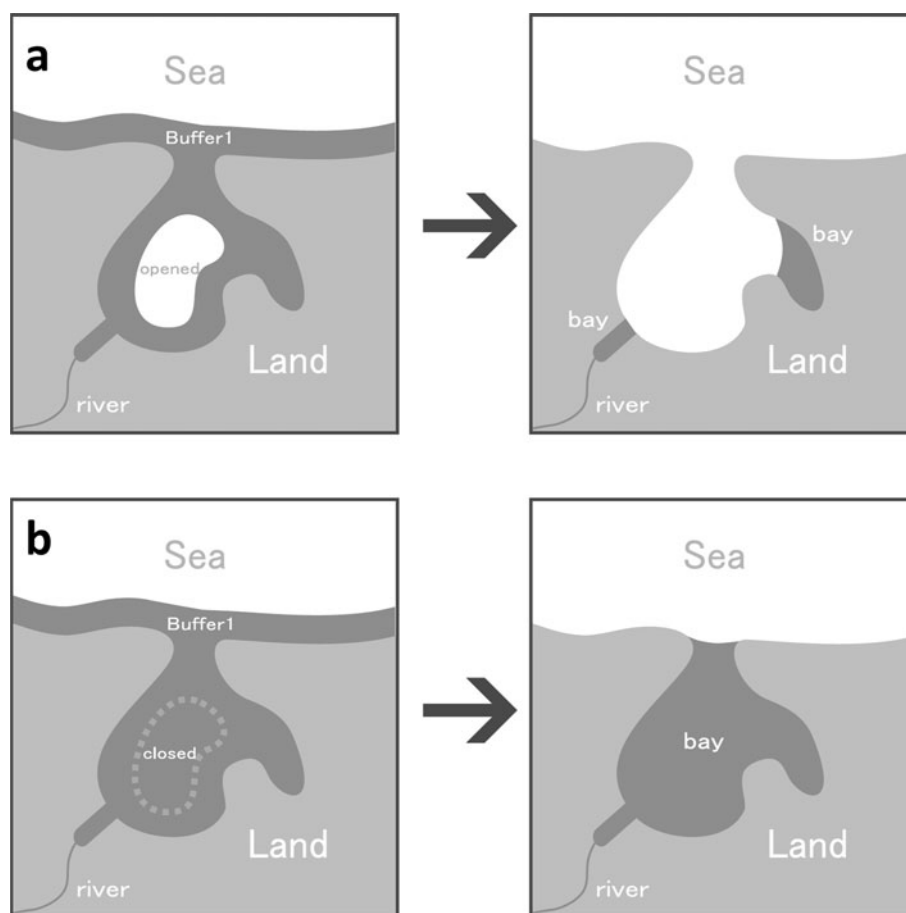


Table 2 AUC-values, sensitivity at the cutoff point, and contribution of each environmental variable to the models

Species	AUC	Cutoff point*	Sensitivity (%)			Contribution (%)											
			All	Suonada	Ariake & Yatsushiro	BC1	BC3	BC6	BO1	BO3	BO6	D1	D3	D6	S1	S3	S6
<i>T. barbatus</i>	0.986	0.0683	97	94	100				7.4	5.5	11.2		67.6				
<i>T. nudicervicus</i>	0.981	0.1564	100	100	100				10.9	8.9	10.7	62.6					

*Maximum training sensitivity plus specificity logistic threshold

T. nudicervicus (3 sites) based on the predicted potential habitat maps, despite there being no previous record. These results demonstrate that poor species distribution data may be covered by potential distributions predicted by SDM based on species distribution information of the data-rich area. In general, the collection of actual presence/absence data is time-consuming for marine organisms (The Oceanographic Society of Japan 1986). In the current study, we demonstrated that SDMs accurately predicted presence predictions, in addition to indicating new areas of distribution for *T. barbatus* and *T. nudicervicus* in the Seto Inland Sea. Therefore, if additional investigations on

distribution of the two species were carried out in this marine area, we would be able to reduce the time and effort requirements, in parallel to enhancing the distribution data, by following the potential distributions predicted by SDMs.

The results of this study show that *T. barbatus* and *T. nudicervicus* inhabit shoal and relatively enclosed waters where tidal flats are easily formed potentially. Such habitats are easily destroyed by various human activities, such as land reclamation (Seino 2000). Therefore, these habitats require conservation management for these two species. In addition, these habitats are probably important for rare species from other taxonomic groups. Therefore, it is

Fig. 4 Response curves for the influential variables in the models of the two species. The probability of presence (logit output) is shown on the y-axis, while the range of the environmental variable is shown on the x-axis

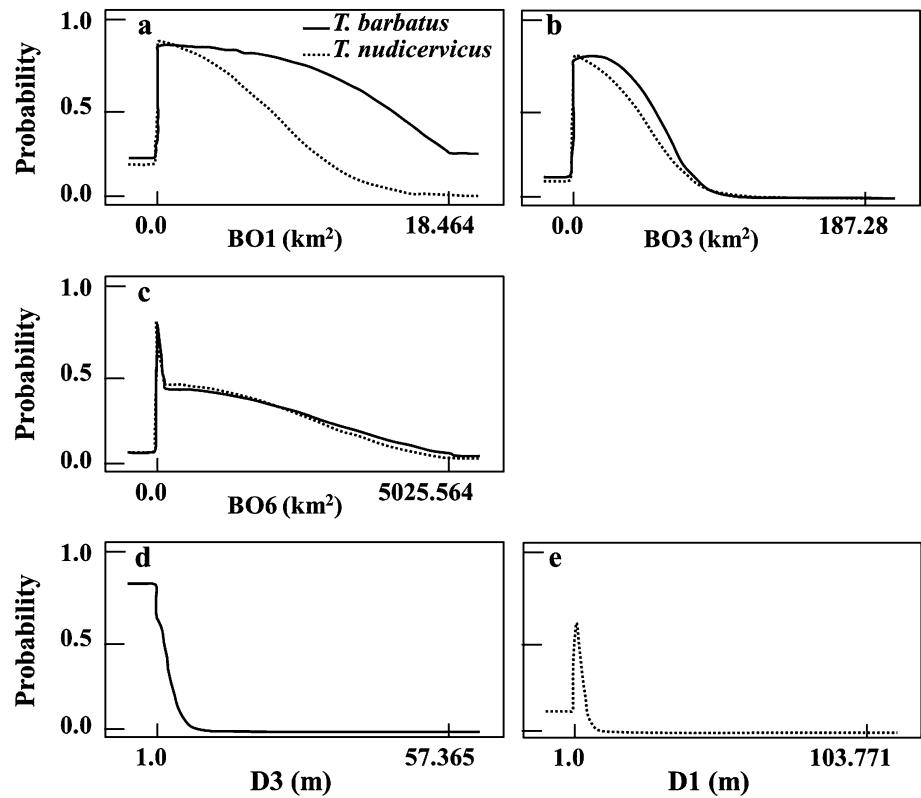
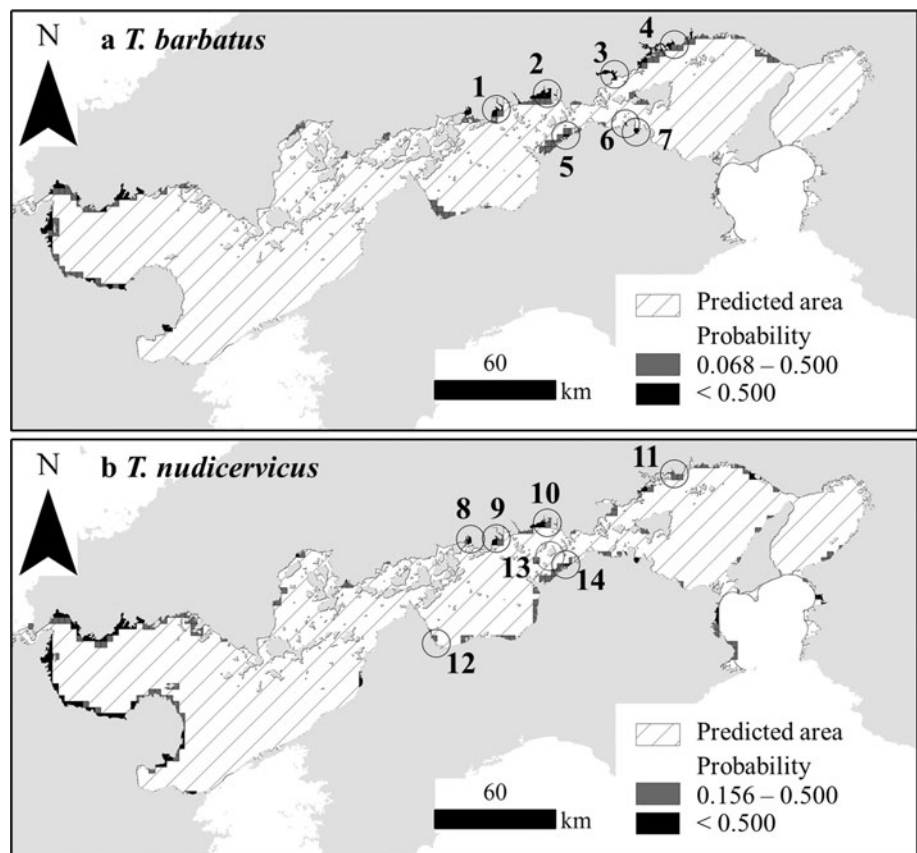


Fig. 5 Potential habitat-distribution maps for the two species. The maximum probability of species occurrence is shown in each 3-km grid. Gray areas show probabilities over a logistic threshold (maximum training sensitivity plus specificity logistic threshold) of less than 0.5. Black areas show probabilities greater than 0.5. Numbered circles from 1 to 14 show the locations of the records in the literature and database, and new records in the present study. 1 Ashida R., Fukuyama, 2 Kurashiki, 3* Kojima Bay, Okayama, 4 Chikusa R., Ako, 5 Marugame, 6 Takamatsu, 7 Sanuki, 8* Matsunaga Bay, Fukuyama, 9* Ashida R, Fukuyama, 10 Kurashiki, 11 Chikusa R., Ako, 12* Shin R., Saijyo, 13 Tadotsu, 14 Marugame. Asterisks indicate records obtained in the present study



important to monitor multiple taxa in these habitats for the effective conservation of the shallow sea ecosystem of the Seto Inland Sea.

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